

Aug. 25, 1942.

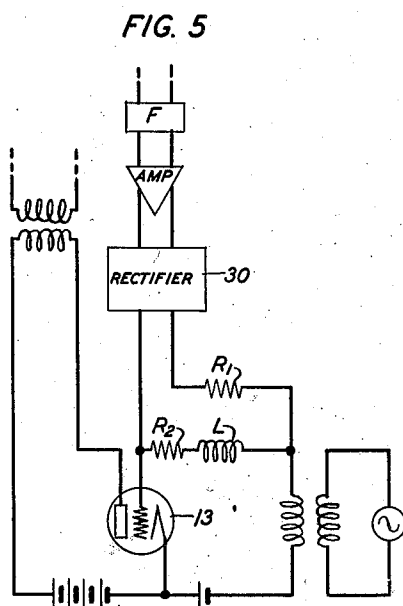
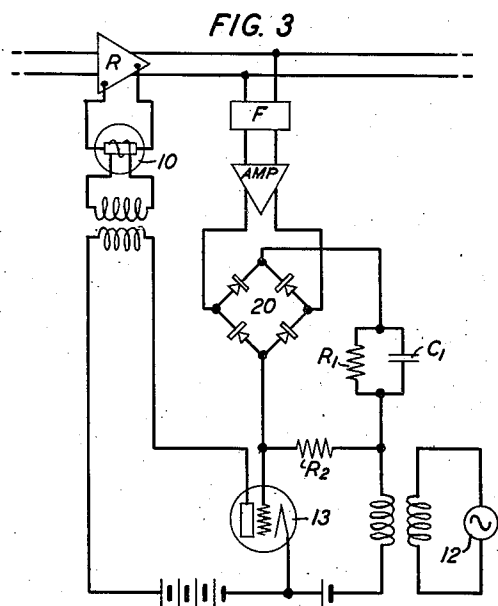
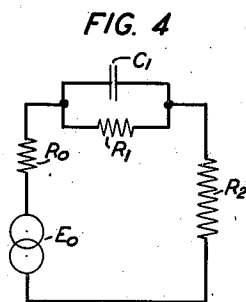
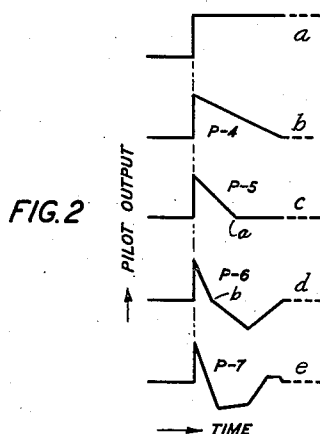
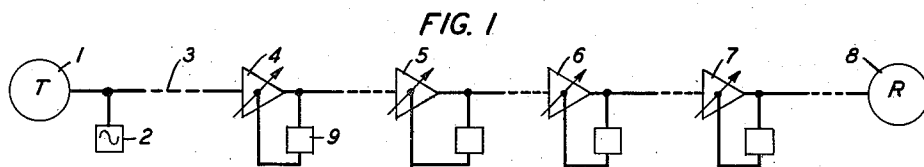
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2,293,750

REGULATION OF REPEATER GAIN

Filed Feb. 5, 1941

2 Sheets-Sheet 1



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FIG. 6

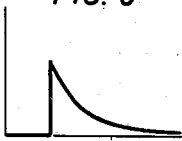


FIG. 7

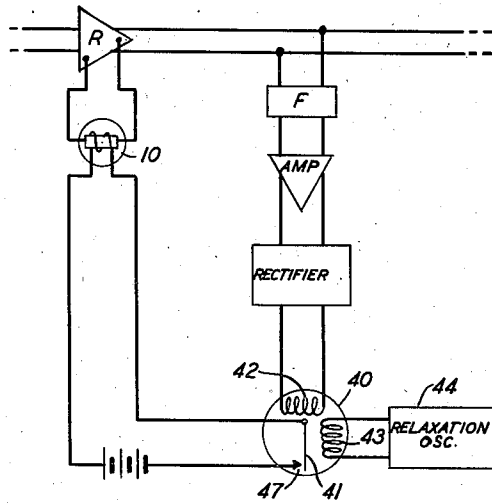


FIG. 8

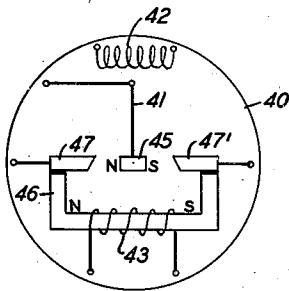
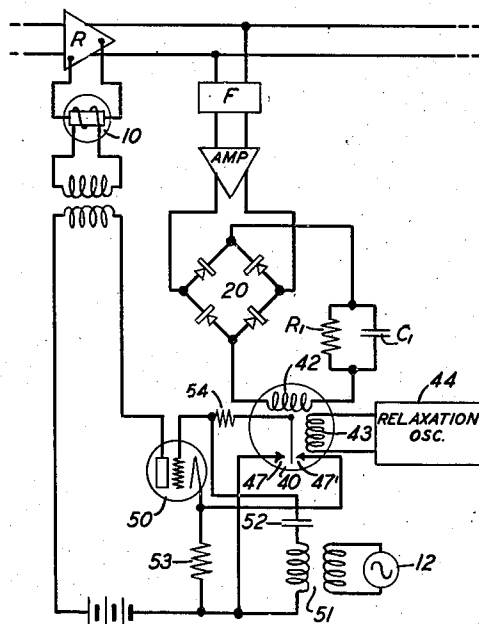
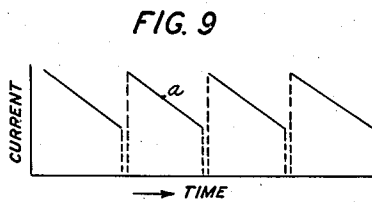


FIG. 10



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REGULATION OF REPEATER GAIN

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Application February 5, 1941, Serial No. 377,427

14 Claims. (Cl. 178-44)

This invention relates to electric wave transmission systems and more particularly to automatic regulation of the transmission characteristics of signal repeaters in a long distance signaling system.

In a typical system of the kind to which the present invention relates, signal repeaters are spaced apart in a long transmission line and the gain or amplification afforded by the several repeaters is automatically so adjusted, under the control of a pilot wave transmitted along with the signal, that the transmission equivalent of each repeater section is maintained substantially constant despite changes in line attenuation or the like. Any change in the intensity of the pilot wave is interpreted at the repeater immediately following the point where the change occurs as calling for a compensating change in the gain of the repeater, such that the intensity of the pilot wave at the output of the repeater is maintained at or restored to its normal value. Inasmuch as the repeater regulators do not operate instantly a sudden change of pilot level at any point in the system will not be compensated immediately by the next repeater but will be communicated to all succeeding repeaters, hence the change in pilot intensity appearing at each repeater is a function not alone of the initial change but of the ensuing regulating action at all of the preceding repeaters. Where there are a large number of repeaters in tandem, it has been observed that the effects described often permit or cause wide transient swings in the gain of many of the repeaters before a proper equilibrium condition is again reached.

One of the principal objects of the present invention is to reduce transient effects in the operation of a repeater regulating system.

Another object of the invention is to reduce or prevent over-shooting or momentary overcompensation for changes in the transmission characteristics of a regulated transmission system.

A further object of the invention is to provide a simplified and improved repeater gain regulator employing an intermittently operated relay.

In accordance with the preferred embodiment of the present invention, the foregoing objects are achieved in a repeater regulator the response characteristic of which is in part a function of the rate of change of the pilot wave or other equivalent control. The nature of the present invention and its various features, objects and advantages will appear more fully from a consideration of the several illustrative embodiments

now to be described with reference to the accompanying drawings.

In the drawings:

Fig. 1 illustrates schematically a line transmission system with pilot wave control of repeater gain;

Fig. 2 comprises a set of diagrams to which reference will be made in the description of Fig. 1;

Fig. 3 illustrates a repeater regulator in accordance with the invention; and Fig. 5 shows a modification thereof;

Fig. 4 comprises an equivalent circuit diagram and Fig. 6 a response characteristic curve which will be utilized in explaining the nature and operation of Figs. 3 and 5;

Fig. 7 shows schematically a repeater gain regulator employing an intermittently operating relay;

Fig. 8 illustrates the relay of the Fig. 7 regulator;

Fig. 9 is a curve diagram pertinent to the operation of the Fig. 7 regulator; and

Fig. 10 shows another form of the invention utilizing the Fig. 8 relay.

Referring more particularly now to Fig. 1 there is represented a system for the transmission of signals from a transmitting terminal 1 at the left to a receiving terminal 8 at the right through a wire line 3 having signal repeaters, such as 4 to 7, inclusive, spaced apart therein. The Fig. 1 system may be, for example, a coaxial conductor system with several hundred repeaters for the transmission of television or multiplex telephone signals. At the transmitting terminal 1 there is a source 2 of pilot current of any suitable high frequency which is transmitted concurrently with the signals and diverted at the several repeaters by the devices 9. The latter comprise means for applying the diverted pilot current to the control of the gain of the individual repeaters. The gain changing function may be accomplished, for example, with the aid of a thermosensitive resistance that is connected in gain controlling relation in the repeater amplifier. Although the invention is readily susceptible of other applications, the several embodiments hereinafter to be described are all specifically adapted for a system of the kind described with reference to Fig. 1.

The response of a repeater regulator to a sudden change in pilot intensity may be rapid but, as previously noted, it is not instantaneous. In the example described with reference to Fig. 1, it is evident that some finite interval is required

for the thermosensitive element to be heated or to cool, as the case may be, to restore normal output conditions following a change in pilot input intensity. In some regulators of this type the gain change introduced in response to an abrupt change in pilot intensity may proceed at a linear rate, that is, at a fixed number of decibels per second, regardless of the extent of the change. In other cases the response may be exponential or otherwise so adjusted that the rate of change in gain is more or less proportional to the departure of the pilot level from normal. In still other cases there may be a brief delay period before any response occurs. Various combinations of these and other response characteristics are possible. That an undesirable transient condition may be established with any of these regulator response characteristics may be evident from brief consideration of the effects obtaining where the response characteristic of each regulator is linear. For this purpose reference may be made to Fig. 2.

Fig. 2 comprises a set of diagrams showing the variation with time of the pilot level at various points in the system following the occurrence of a fault. It may be supposed that at some point in the system preceding repeater 4 there occurs a fault of such nature that the pilot intensity abruptly rises to a higher value than normal, and that this change in pilot intensity appears at the input of repeater 4, as represented by Diagram *a*. Diagram *b* indicates the variation in pilot intensity at the output of repeater 4 as the regulator associated therewith proceeds to reduce the gain of the amplifier, and the pilot and signal intensity as well, at the assumed linear rate, of say m decibels per second. The time interval indicated may represent, for example, the time required to heat a gain controlling thermistor in repeater 4 to the required temperature to reestablish normal output intensity. Diagram *b* represents also the pilot intensity variation appearing at the input of repeater 5. The regulator associated with repeater 5 immediately begins to reduce the repeater gain at a rate m but inasmuch as the pilot input is decreasing at rate m , the pilot output intensity decreases at twice that rate or $2m$. Accordingly, normal pilot output intensity is achieved, at point *a* of Diagram *c*, while the pilot input is still diminishing at the rate m . As the diminishing pilot input tends to cause the pilot output to fall below normal output intensity at the same rate m , the regulator interprets this as requiring an increase in gain of the repeater, hence the thermistor is allowed to cool at a rate which will be supposed to be the same as the heating rate m . Accordingly from point *a* forward, the repeater gain is increased at the same rate as the pilot output is diminishing and the pilot output therefore remains constant at its normal output value and the regulating action ceases when the pilot input ceases to diminish.

At repeater 6 the pilot input diminishes at a rate $2m$ in accordance with Diagram *c* and the regulator operates to accelerate, to a rate $3m$, the fall in pilot output intensity. At point *b* of Diagram *d* the pilot output is reduced to normal value, but the pilot input continues to fall at a rate $2m$. Whereas again the regulator interprets the continued fall of pilot input as requiring increase of repeater gain, the rate of fall $2m$ is greater than the rate m at which the pilot regulator can operate. Hence the pilot output continues to fall at a reduced rate m until the

point *a* of Diagram *c* is reached, whereupon the regulator restores the pilot output, at a rate m , to its normal value.

The foregoing should suffice to show that with many repeaters in tandem the pilot intensity may fluctuate in a manner quite unlike that introduced at the point of fault and that the transient effect is due at least in part to inability of the regulator to respond quickly to a sudden change in pilot intensity. Diagram *e* shows in like manner the next step in the building of a transient variation in pilot intensity. Eventually the transient peaks may exceed the initial change in pilot intensity.

Referring now to Fig. 3 there is shown an improved repeater regulator in accordance with the present invention. The repeater amplifier R has associated with it in gain controlling relation a silver sulphide element or other suitable thermistor 10 that is heated by current applied from source 12. The latter may be, for example, a source of thousand-cycle current. Between thermistor 10 and source 12 is an amplifier comprising a triode tube 13 the gain of which is variably adjusted by the potential applied to the control grid thereof.

At the output of repeater amplifier R, pilot current is diverted by a filter, amplified as desired, and applied to the input terminals of a full wave rectifier 20. From the output terminals of rectifier 20 a pair of leads extends to the respective terminals of a resistor R_2 that is interposed in the control grid lead of amplifier tube 13, and in one of the rectifier leads there is interposed a combination comprising a resistor R_1 shunted by a condenser C_1 . In response to slow changes in pilot output intensity, the rectified voltage appearing at the control grid varies in like manner, and the consequent changes in heating current supplied to thermistor 10 operate to change the resistance of the thermistor in such sense and degree as to effect a compensating change in the gain of amplifier R.

The operation of the Fig. 3 regulator may be better understood on reference to the equivalent circuit diagram of Fig. 4. In the equivalent circuit, the output voltage of rectifier 20 is represented by the source of E_0 and the resistance of the rectifier by series resistor R_0 . The latter is connected in series with the parallel combination of R_1 and C_1 and with resistance R_2 . As long as there is no change in the output intensity of the pilot, and therefore also of the voltage output of the rectifier 20, the portion of the rectifier voltage E_0 that appears across resistance R_2 is a fixed fraction measured by the ratio of R_2 to the total series resistance in the Fig. 4 circuit. The same relation holds for variations in pilot intensity that are so slow that the presence of condenser C_1 has no appreciable effect. Whenever the pilot intensity and rectifier voltage are changing rapidly, however, condenser C_1 exerts a shunting effect on resistance R_1 and therefore a greater percentage of the rectifier output voltage appears across resistance R_2 . The shunting effect of condenser C_1 depends, of course, on the rate of change and for an instantaneous change such as represented by diagram *a* of Fig. 2, the shunting effect is complete. It should be evident that the voltage change impressed across R_2 is greater, the more rapid the initial change in pilot intensity and that the change in heating current to thermistor 10 is similarly accelerated.

An important feature of the Fig. 3 regulator

is that following the initial sudden change in voltage across R_2 and the initial correspondingly sharp change in the gain of the repeater amplifier, the ultimate gain adjustment is approached asymptotically as the condenser C_1 charges or discharges as the case may be. Thus, abrupt changes in pilot level that tend to produce serious transient effects are quickly, approximately compensated by the regulator, followed by accurate compensation at a rate not calculated to give rise to further transient effects.

Fig. 6 shows a curve diagram comparable with diagram *b* of Fig. 2 illustrating qualitatively the response of the Fig. 3 regulator to a step change in pilot intensity.

In the modification of the Fig. 3 regulator that is illustrated in Fig. 5 an inductance L is interposed in series with resistance R_2 and the resistance R_1 in the output lead from pilot rectifier 30 is unshunted. When the rectifier output is constant the gain-controlling bias applied to the control grid is determined simply by the ratio of resistance R_2 to the total resistance in the rectifier output circuit, but when the rectifier output changes, in response to a change in pilot level, the effective biasing voltage is increased by the voltage drop due to the reactance of inductance L . In response to an abrupt change in pilot level, therefore, there is a corresponding quick change in the voltage applied to the control grid of amplifier tube 13, followed by gradual approach to the new steady-state condition.

Fig. 7 shows a repeater gain regulator in which the heating of a gain-controlling thermistor 10 is controlled by an electromechanical relay 40. The operating winding 42 of the latter is connected to the output of an amplifier-rectifier which is supplied with pilot current diverted from the output of the repeater amplifier R . Relay 40 has also a resetting or biasing coil 43 for controlling the relay operation as will presently appear. The relay is preferably of a construction illustrated in Fig. 8 which may conveniently be described as a modification of the "Sensitrol" relay manufactured by the Weston Electrical Instrument Company.

Referring now to Fig. 8, the relay 40 comprises a direct-current meter and is illustrated schematically as comprising the usual pointer 41 and operating winding 42. At its free end the pointer 41 carries a small permanent bar magnet 45 which is disposed cross-wise of the pointer and adapted to swing between soft-iron members 47 and 47'. The latter are electrically insulated from each other and are adapted to serve as stationary contact members of the relay, while pointer 41 and magnet 45 provide the movable contact member of the relay. The several contact members may be plated with silver or low resistance contact metal. Movement of the pointer, induced by changes in the current in operating winding 42, may place bar magnet 45 so close to one or the other of the soft-iron members that it is attracted thereto and held firmly in contact therewith despite further changes in the current in winding 42.

To effect release of the contact, a soft-iron core member 46 is provided and the members 47 and 47' are arranged as pole-pieces in magnetic circuit therewith to form a generally C-shaped structure. The members 47 and 47' are electrically insulated from each other by insulation separating them from core member 46. The latter carries a winding 43 through which unidirectional current may be passed to establish a mag-

netic field through the C-shaped structure. The polarity of this field is such that it tends to repel by magnetic action, the bar magnet 45, and when the field is strong enough it forces the latter away from contact with either of the members 47 and 47'.

Referring again to Fig. 7, winding 43 of relay 40 is connected to the output of a relaxation oscillator 44 which comprises a gas-filled tube or is otherwise arranged in known manner to produce continuously an effectively saw-toothed wave such as represented diagrammatically in Fig. 9. When the pilot output of repeater R is of normal intensity, the rectified current in relay winding 42 tends to move pointer 41 to make contact with pole-piece 47, and thereby to close a circuit comprising the heater element of thermistor 10 and a source of heating current. Once in each cycle of the relaxation oscillator, the upward surge of current produced therein is sufficient to overcome the magnetic attraction and thereby to break the relay contact by repelling the pointer. Following the initial surge, the oscillator current gradually diminishes until a point *a*, indicated in Fig. 9, is reached such that the current in winding 43 is no longer able to overcome the counter-force exerted by winding 42 and the magnetic attraction between the pointer magnet 45 and pole-piece 47. Thereupon the relay contact is made again and heating current is supplied to thermistor 10 until the next upward surge of current in the oscillator cycle is reached.

It will be evident that the position of point *a* along the oscillator current characteristic will depend on the current in winding 42, and that closing of the relay contact will therefore be more or less deferred depending on the pilot level at the output of the repeater. Thus if the pilot level is low, the relay contact is closed for a longer period than normal, more heat is supplied to the thermistor 10 during each cycle of the oscillator and the increased temperature of the thermistor 10 can be translated into a corresponding compensating increase in the gain of repeater amplifier R . The heat capacity of thermistor 10 and the thermal insulation from its surroundings can be so adjusted that the temperature of the thermistor does not substantially change from one cycle to another of the relaxation oscillator. The period of the latter may be, for example, a few seconds or a fraction of a second, and in general it should be short enough that the pulses of heat supplied to the thermistor 10 yield a substantially integrated or average value. If desired, the tendency of the relay to produce pulses of heating current may be offset by an electrical integrating circuit that is a feature of the regulating system to be described with reference to Fig. 10.

In Fig. 10 the relay 40 illustrated in Fig. 8 is controlled by rectified pilot current as before and operates to control the gain of an amplifier 50 interposed between the gain regulating thermistor 10 and a source 12 of heating current therefor. The amplifier 50 is connected to heating current source 12, which may provide thousand-cycle current, through an input transformer 51 the secondary winding of which is connected to the control electrode of the amplifier tube through a condenser 52 and to the cathode thereof through a resistance 53. The output circuit of the amplifier comprises an output transformer and an anode voltage source that is connected to the cathode through resistance 53. The pointer of relay 40 is connected through a resist-

ance 54 to the control grid of the amplifier tube 50, relay contact 47 is connected to the terminal of resistance 53 that is connected to the input transformer, and relay contact 47' is connected to the cathode.

The circuit constants in this case are so adjusted that when the pilot output intensity is normal, the relay pointer tends to assume a neutral position midway between the contact members 47 and 47'. Under the influence of the varying current in relay coil 42 and current from the relaxation oscillator in coil 43, the relay pointer is moved intermittently from one contact to the other, dwelling at each contact for a period determined by the level of rectified pilot current. When relay contact 47 is closed, resistor 54 is thereby connected from the grid of amplifier 50 to the lower end of resistance 53. By virtue of the anode biasing current flowing in resistance 53, the lower end thereof is negative with respect to the cathode and the negative bias thereby impressed on the grid reduces the amplification factor or gain of the amplifier 50. At the same time the voltage drop across resistance 53 causes charging current to flow into condenser 52 by way of the relay contact 47 and resistance 54.

When relay contact 47 is broken and contact 47' is made, the grid biasing connection of resistance 53 is broken and the charge on condenser 52 is dissipated through resistances 53 and 54 and relay contact 47'. Noting that the charge on condenser 52 contributes at all times to the biasing of the amplifier grid, the charging and discharging circuit of the condenser 52 may be so proportioned that the net biasing voltage on the grid is substantially constant as long as the pilot intensity does not change.

As in Fig. 3, the regulator of Fig. 10 is provided with a resistance and condenser combination R_1C_1 which makes the response of the regulator a function of the rate of change of pilot intensity. The combination is connected in the output circuit of pilot rectifier 20 in series with the operating winding 42 of relay 40. When the pilot output is at its normal value, the voltage across operating winding 42 is a fixed fraction of the total output voltage of the rectifier 20 determined by the ratio of the resistance of winding 42 to the total resistance in the rectifier output circuit. Winding 42 in this respect corresponds to resistance R_2 in Fig. 4. Because of the presence of the resistance-condenser combination R_1C_1 a sudden change in pilot output intensity produces a corresponding large change in the proportion of the rectifier output voltage appearing across winding 42. So long as the rectified voltage is above or below its normal value, the pointer of relay 40 dwells a greater or lesser time on contact 47 during each cycle of the relaxation oscillator. The average value of heating current supplied to thermistor 10 is correspondingly varied to restore the pilot output to its normal intensity.

In an illustrative case, the combined output resistance of rectifier 20 and of relay winding 42 may be 2,000 ohms, resistance R_1 , 100,000 ohms; and the capacitance of condenser C_1 , 10 microfarads. In some cases it may be found desirable to reduce the spacing of the relay contacts 47 and 47' and to reduce the period of the relaxation oscillator substantially below the values hereinbefore suggested.

Although the present invention has been described principally in terms of several typical embodiments, it will be understood that these embodiments are only illustrative and that the

invention is susceptible of other forms and applications within the spirit and scope of the appended claims.

What is claimed is:

1. A transmission line carrying signal and pilot currents, a signal repeater in said line and means for modifying the gain of said repeater as a function of the time rate of change of said pilot current.
2. A system for the distant transmission of signal and control currents, a multiplicity of signal repeaters in said system defining a plurality of repeater sections, means individual to said repeaters for regulating the gain thereof under the control of said control current to maintain the transmission equivalent of each of said repeater sections substantially constant, said regulating means including means for accelerating the response thereof to rapid changes in said control current.
3. In combination with a signal repeater, means for automatically adjusting the gain of said repeater in accordance with the intensity of a control current, means for supplying said control current to said gain adjusting means and means for accelerating the gain adjusting response of said regulating means in proportion to the rate of change of said control current.
4. A repeater gain regulator comprising means for receiving unidirectional control current of varying amplitude, a reactor for modifying the time rate of change of said unidirectional current and gain regulating means responsive to the modified control current.
5. A signal transmission line, a signal repeater in said line and a gain regulator for said repeater, said regulator comprising means for deriving unidirectional gain-controlling current from said line, a circuit element of variable impedance connected in gain-controlling relation in said repeater, means for modifying the impedance of said element in accordance with the intensity of said unidirectional current, and reactance means for varying the intensity of said current in proportion to the time rate of change thereof.
6. A transmission line carrying signal and pilot currents, a repeater in said line, a gain regulator for said repeater comprising means for deriving unidirectional current proportional to the intensity of said pilot current at said repeater, a series circuit traversed by said unidirectional current and comprising a resistance and a capacitance in parallel with each other and an impedance element, a gain modifying element in said repeater and means for varying the said gain modifying element in accordance with the voltage across said impedance element.
7. A signal transmission line carrying signal and pilot currents, a repeater in said line, a gain regulator for said repeater comprising means for deriving unidirectional current proportional to the intensity of said pilot current at said repeater, a circuit comprising an impedance element traversed by said unidirectional current, an inductance and a resistance shunted across said circuit in series with each other, a gain modifying element in said repeater, and means for varying the said gain modifying element in accordance with the voltage across said impedance element.
8. A combination in accordance with claim 6 in which said last-mentioned means comprises a space discharge amplifying device controlled by said voltage.

9. A combination in accordance with claim 7 in which said last-mentioned means comprises a space discharge amplifying device.

10. A combination in accordance with claim 6 in which said impedance element comprises an electro-mechanical relay.

11. In combination with a signal repeater, a thermistor connected in gain regulating relation to said repeater, means for supplying heating current periodically to said thermistor, means for varying the portion of each period that heating current is supplied to said thermistor, and means for supplying control current to said varying means.

12. A combination in accordance with claim 11 including means for maintaining the temperature of said thermistor substantially constant from one period to another.

13. A combination in accordance with claim 11 in which said thermistor is so proportioned and arranged that the temperature thereof remains substantially constant from one period to another.

14. In combination with a signal repeater, a thermistor connected in gain regulating relation to said repeater, a source of heating current for said thermistor, means operating substantially periodically to control the supply of heating current from said source, means for varying the portion of each period that the control is exercised by said operating means, means for supplying control current to said varying means, and electrical means for reducing periodic variations in the heating current supplied to said thermistor.

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